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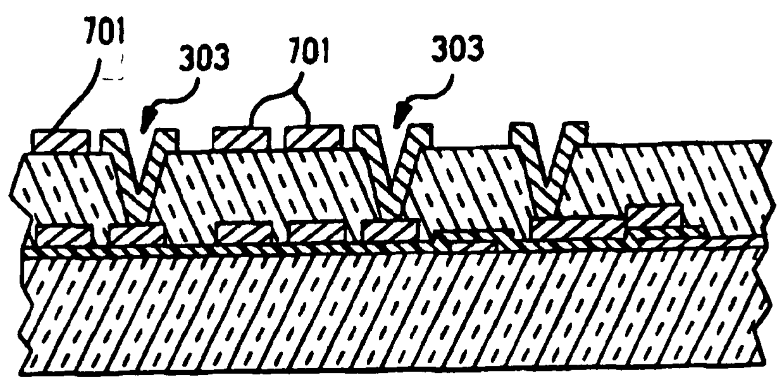
(54) Title: RF TRANSFORMER USING MULTILAYER METAL POLYMER STRUCTURES

(57) Abstract



A transformer for high frequency applications having a multilayer thin film structure and a dielectric material disposed between coils increases the inductive coupling between the coils while at the same time reducing the capacitive coupling between the coils of the transformer. A glass substrate (201) has a first metal spiral (301) deposited thereon, and a layer of polymer insulator (601) is deposited thereon encapsulating the first metal spiral. A second metal spiral (701) is deposited on the layer of polymer and the process continues with a next layer of polymer material. The interconnection of the metal spirals to one another in the different layers is effected by the use of selectively etched grooves having vias (902) deposited therein. The present invention is specifically drawn to a balun transformer. The use of the polymer preferably BCB as the dielectric has the functional advantage of very low loss due to absorption at microwave and rf frequencies, and yet this insulator allows for excellent inductive coupling while reducing greatly the capacitive coupling among the various layers of the device.

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RF TRANSFORMER USING MULTILAYER METAL POLYMER STRUCTURES

The invention of the present disclosure relates to transformers for high frequency application made by standard etching and deposition techniques.

Advances in high frequency and function integrated circuits has led to interconnection and packaging technologies being the limiting factors for system performance. Accordingly, there has been a focus on improving system performance by improving interconnection and packaging of the devices of the system.

In the realm of rf, microwave and millimeter wave technology, performance of systems has been improved through a variety of means. The present invention being focused on transformers, the discussion of the prior art will be so focused as well. To this end, the recent technology in transformers and inductors has been via thin film technology. The basics of thin film technology as applied to transformers is as follows. In general, a dielectric substrate has deposited thereon a metallic pattern to effect the required inductors for the transformer. Thereafter, a layer of dielectric is deposited. The transformers fabricated using thin film technology are known to have primary and secondary coils in a side-by-side arrangement as well as a multi-level arrangement. A driving factor in the design of the transformer is the Q factor of the system. The Q factor is a measure of the energy conversion efficiency

the Q-factor is given by:

$$Q = \omega L/R$$

where ω is the angular frequency, L is the total inductance and R is the resistance of the coil. As can be appreciated, the Q factor can be increased by increasing L and decreasing R to the greatest extent possible for a given value of ω.

In a thin film transformer as well as other transformers, a time dependent variation in the current in the primary windings or coil results in an induced current in the secondary windings. The induced current is proportional to the number of turns in the secondary coil. Furthermore, the larger the number of turns in the primary coil, the greater is the magnetic field density generated by the primary coil, leading to a greater induced current in the secondary coil. Accordingly, a transformer which induces current by means of mutual inductance between the primary and secondary coils, the larger the number of turns of the coils, the higher is the magnetic field intensity generated by each of the coils so that the inductance between the coils is increased. Thus, the coupling between the coils and the corresponding energy conversion is increased.

An increase in L requires among other factors, an increase in the number of turns of the primary and secondary coils, which serves often to increase the area of the transformer itself. Beyond the obvious desire to reduce the required space of the individual elements of a circuit, such an increase in area also increases

serves to reduce high speed performance capabilities. Furthermore, increasing the number of windings to increase inductance increases the length of the conductor which increases resistance and lowers Q value.

Accordingly, it is desired to have a transformer with an increased inductance and a reduced resistance to optimize the Q factor at higher frequencies.

An example of a transformer based on thin film technology is disclosed in U.S. Patent 5,420,558 to Ito et al. The reference to Ito et al. discloses a number of different configurations of transformers based on thin film technology. However, the transformers as recited in the reference to Ito et al. discloses the use of silicon dioxide as the dielectric material between coil layers. SiO_2 has limited application to a thin film transformer because of its process thickness limitation. Using thin film deposition techniques, SiO_2 can be deposited in layer thicknesses on the order of 2 μm. Deposition of silicon dioxide in thickness greater than this amount results in excessive mechanical stress in the film that adversely affect structural reliability. The disadvantage of using silicon dioxide as the insulator is, among other disadvantages, its relatively high dielectric constant and the inability to provide layers of thicknesses greater than the above mentioned. To this end, the capacitance between the transformer windings at different layers on a vertically stacked transformer is directly proportional to the dielectric constant and inversely proportional to the distance between the windings (hence the thickness of the

optimize the magnetic coupling between transformer coils, whereas electric coupling through capacitive coupling is not desirable. To this end, as every inductor having a time varying current therein has an intrinsic capacitance, the greater this capacitance the smaller is the bandwidth of functional use. In particular at rf and microwave frequencies, the capacitive coupling will result in an equivalent circuit consisting of the inductor in parallel with the intrinsic capacitor, a passive electronic resonator. At resonance the LC circuit tends to radiate resulting in substantial losses, thus making it desirable to avoid resonance.

Accordingly, in the case of an inductor or transformer it is desirable to reduce greatly the intrinsic capacitance as much as possible to increase the useable band for the transformer by increasing the resonance frequency of the resonator beyond a useable frequency. In order to reduce as much as possible the effects of capacitive coupling in the transformer, it is desirable to increase the distance (and thus the thickness of the insulator) between the coils at different levels and decrease the dielectric constant of the insulator. Therefore, what is desired is a transformer that achieves the desired small size, and yet achieves the desired inductive coupling between coils while not being susceptible to capacitive coupling between the coils.

In accordance with the above described transformer for high frequency applications, a transformer is described in the instant disclosure having a multi-layer thin film structure having a low dielectric constant material disposed between the coils that minimizes capacitive coupling between the coils of the transformer.

To this end, a glass substrate has a first metal spiral deposited thereon. After this deposition, a layer of polymer insulator, preferably benzocyclobutene (BCB) is deposited, encapsulating the first metal spiral. A second metal spiral is deposited on the BCB layer, and any required interconnection is effected by the use of vias which are selectively opened in the BCB. This process of metal spirals separated by BCB and interconnected as necessary by vias is continued until the desired number of turns in the primary and secondary coils is achieved. It is important to note that for ease of discussion the transformer described will have three layers of metal windings with: a substrate, a first metal coil winding, a first layer of polymer, a second layer of coil windings, a second layer of polymer, a third layer of coil windings and a third layer of polymer. It is clearly within the purview to have a greater or lesser number of layers depending on the desired circuit. That is to say the process of fabrication is applicable to other circuits and structures.

The use of a polymer, preferably BCB as the dielectric between the coils has the functional

rf and microwave frequencies, and yet this insulator allows for excellent inductive coupling while reducing greatly the capacitive coupling. Additionally the polymer allows the use of processing steps in the fabrication of the transformer that result in ease of manufacture and reliability of result. To this end, the polymer is relatively smooth for ease of metal deposition and readily processed using standard large scale IC processing techniques.

The transformer that results through the preferred materials and processing steps can be made in very small dimension and in large scale production. The ill effects of parasitic elements such as capacitance having been reduced, operational transformer frequencies in the rf and microwave spectra are readily realized.

It is an object of the present invention to have high frequency, low cost small size transformers fabricated in large quantity.

It is a feature of the present invention to have a multi-layer vertical structure transformer selectively interconnected by way of vias.

It is a further feature of the present invention to have a transformer having low capacitive coupling, and high inductive coupling between transformer windings.

have a low loss insulator at high frequencies in the transformer.

It is an advantage of the present invention to have a transformer fabricated with materials that are readily adaptable to conventional processing techniques.

Invention will now be described by way of example with reference to the accompanying drawings in which:

Figure 1 is a schematic diagram of a balun transformer.

Figure 2 is a plan view of a balun transformer fabricated by the present invention.

Figures 3-10 show cross-sectional views of the fabricated transformer by the present invention in selected sequential steps of the process.

Figure 11 is a schematic circuit diagram of a mixer using balun transformers.

As stated previously, the invention of the present disclosure relates to a transformer fabricated using multilayer process technology with a polymer dielectric offering advantages in size, cost, reliability of the device as well as ease of manufacture in large scale. Common to all transformers envisioned in the present invention is the use of a multilayer device which is

the purview of the present invention are balun transformers, directional couplers, quadrature hybrids, and power dividers. A feature of the invention of the present disclosure is the ability to effect various circuits by application of the basic process of the invention. That is to say that by the selective placement of the metal lines, vias, bond pads and other required elements by the process steps described herein enables the fabrication of devices for use at high frequency with the described advantages of high inductive coupling and low capacitive coupling.

The miniature transformer circuits of the present device are preferably less than $1mm^2$ allowing for very large scale manufacture on a single glass substrate wafer.

For ease of discussion, an embodiment of the present invention drawn to a balun transformer will be described. As stated, the present invention has other applications, and the balun is merely described in detail for exemplary purposes. To this end, the circuit of the desired transformer is effected by selective placement of the spirals, vias, bonding and circuit elements such as capacitors by the process of the present invention described herein. Clearly, the desired interconnection is effected by the selective placement of the elements and vias and circuits within the purview of the artisan of ordinary skill are readily fabricated through the teachings of the present disclosure. The schematic of a typical balun transformer is shown in Figure 1. A balun transformer

single ended input into a pair of differential outputs having equal amplitude and opposite phase. To this end, when a voltage V is applied to the single ended input terminal 101 voltage is output at the first output terminal 102, while an equal voltage of opposite polarity is output at 103, the second output terminal. For a time varying input, the outputs at 102 and 103 are of opposite phase. For an input signal that is unbalanced to ground (reference terminal at zero potential relative to ground), the instantaneous output average voltage is thus zero. Conversely, a balanced signal applied across the two output terminals will appear as an unbalanced signal across the input terminal, thus the designation "balun". Balun transformers have application in single and double balanced mixer applications as well as other applications in heterodyne transceiver systems.

Turning to Figure 2, the plan view of a balun transformer fabricated by the process of the present invention is shown. To this end, the input bond pad 201, the input ground pad 202, the output ground pads 203 and the output bond pads 204 and 205 are located on the surface of the substrate. The transformer windings in Figure 2 are those of the top layer of the transformer, with three windings 205,206 and 207 located directly above the windings of the lower two layers of the transformer (and thus not seen). This structure allows for a desired number of turns that enable a higher inductance value, while not sacrificing Q value due to current crowding. That is to say, if the open

through the plane of the spiral) is decreased too much, there is a corresponding reduction in the Q value. Therefore, the benefits of reduced size must be weighed against the reduction in the Q factor for the reasons above stated. Finally, the number of turns in fact increases the inductance, but also increases the capacitive coupling between two layers which reduces accordingly the self resonant frequency of the transformer. Accordingly, the number of turns must be determined balancing the benefit of increased inductance against the detriment of increased capacitive coupling. Further details of the above described are found in *Processing and Electrical Characterization of Multilayer Metallization For Microwave Applications*, International Conference on Multi-Chip Modules, April 1995.

Figure 10 shows the transformer in cross section along the line X-X' of Figure 2. To this end, the transformer windings are shown in three layers at 1001 through 1011 with the vias 1012 providing the interconnection between the layers of the transformer.

Turning to Figures 3 through 9, the process of the manufacture of the preferred embodiment of the invention, a balun transformer, is discussed. As stated earlier, other transformers are envisioned and the balun is merely discussed for exemplary purpose for ease of discussion. The glass substrate is preferably borosilicate and has a dielectric constant of about 4.1, and a loss tangent on the order of 0.002 at microwave frequencies. To aid in the deposition of the fine lines for the first metal layer the amorphous glass substrate

shows the deposition of the metal for a bond pad 301 and a capacitor 302 for the balun transformer. All metal layers of the present invention are fabricated by standard lift-off techniques, eliminating the need for metal etching and the drawbacks of undercutting that arise through etching. The lift-off techniques require the use of a suitable photoresist having a negative profile, and standard evaporation techniques are used to deposit the metal. The negative profile of the photoresist is obtained while reversing the polarity of the resist with a post-exposure bake. Since evaporated metal is deposited in a direction orthogonal to the substrate surface, the negative profile of the resist ensures a break between the metal on top of the resist and metal on the substrate. The metal on the resist is then removed with a water jet, and the resist is stripped thus leaving behind a clean metal pattern on the substrate. The metal lines of the transformer of the present are on the order of 25 microns wide and are 2-5 microns thick. The metal layer of the first layer is preferably Ti-Pt-Au-Ti and is used for the wire bond pads 301, the lower capacitor plates 302 and the underpass conductors. Titanium is used to enhance adhesion, Pt is used as a diffusion barrier and Au is used for compatibility with standard wire-bond processes. For the coil windings and capacitor top plates, the preferred metal scheme is Ti-Pt-Ag-Pt-Ti. Less preferably, gold can be used in place of silver but affects the price of the processing. Furthermore, other metal schemes are possible for use as the metal lines.

possible and within the purview of the invention.

With the deposition of the first metal layer as shown in Figure 3, the deposition of a suitable dielectric 401, preferably silicon nitride is effected. As shown in Figure 4 the SiN film acts as an insulator for the capacitor 302, and for the cross-overs. The SiN film is deposited by PECVD (Plasma Enhanced CVD) at 300° C. Thereafter standard photolithigraphic and plasma etching techniques are used to etch the SiN film 401 wherever electrical contact is required. After the completion of the first metal layer, the metal transformer windings 501 of the first layer of the transformer is effected by the above described technique.

After the completion of the SiN film deposition, the first layer of polymer insulator 601 is deposited. This layer is preferably BCB, although other materials such as photosensitive or non-photosensitive polyimides will suffice. After the BCB layer is deposited, the Vias for interlevel connection as well as bond pad connections is effected. The deposition of the BCB as well as the Via etching is effected by the techniques disclosed in "*Processing and Microwave Characterization of Multilevel Interconnects Using Benzocyclobutne Dielectric*", by P. Chinoy and James Tajadod, IEEE Transactions on Components, Hybrids and Manufacturing Technology, Vol. 16, No. 7, Nov. 1993 and *Processing and Electrical Characterization of Multilayer Metallization For Microwave Applications*, International Conference on Multi-Chip Modules, April 1995. As stated

relatively low value and has a dielectric constant on the order of 2.65, with the attendant advantages to transformers as discussed above. The layers of BCB are deposited preferably in a thickness of 3 microns, although the layers can be as thick as 20 microns. Furthermore, the BCB has a low moisture coefficient (on the order of 0.1%) which in addition to the advantages stated in the articles to Chinoy, et al. above has the advantage of ensuring that electrical properties do not change with the environment as well as makes it compatible with Ag metallization which is very reactive to water. Finally, it is of interest to note that two types of BCB are envisioned in the invention of the present disclosure. A first version is photosensitive in which case the Vias 602 can be directly patterned by exposure to light, and a second non-photosensitive version in which case the Vias 602 are plasma etched through a photoresist or metal mask. The former is easier to process and the latter gives better planarization and thicker coatings. The better planarization allows for finer metal lines, and the thicker layers reduce capacitive coupling. In the instant invention, the preferred technique is to deposit the lower two layers of polymer, for example BCB, that are photosensitive for ease of processing, while the top layer is non-photosensitive polymer, preferably BCB to planarize the entire structure of the transformer.

The remaining layers of the transformer are effected by repeating the above techniques. To this end, Figure 7 shows the completed metallization of the

second layer. As shown in Figure 8, the next layer of BCB 801 is deposited and etched Vias 802 are effected. Finally, the third layer of windings 901 are deposited as shown in Figure 9, and the Vias are metallized as shown at 902 and a final layer of BCB 1013 is deposited as shown in Figure 10 with vias etched as at 1014. The metallized vias 303 and 902 etched in layers 601 and 801, respectively provide electrical connection between the coil windings 501,701 and 901 as the circuit of the transformer requires. The Vias 1014 open up wire bond pads and saw streets to facilitate the dicing or sawing of the wafer into individual die or circuits. Finally, the ground plane 1015 of the transformer is effected by deposition of metal on the lower surface of the glass substrate.

The preferred embodiment, a balun transformer, is fabricated as follows. The bond pad 301 and lower plate of the capacitor 302 have disposed thereon a layer of SiN. Thereafter the coil windings 501 and upper plate of the capacitor 502 as well as the cross-over 503 are deposited. This forms the V- output 103 of the transformer. The resonating capacitors are further formed where the coil winding 501 and cross-over 503 overlies the bond pad 301 and lower plate of the capacitor 302. The metal coils 701 are then disposed to effect the input winding by way of the Via 303

Finally, the Via 902 effects the V+ output winding 102. Figure 11 shows a typical use of a balun transformer in a transceiver circuit. To this end, the balun 1104 is connected to a silicon schottky ring quad

In operation, the high frequency signal from the rf input 1102 is mixed with a slightly lower frequency from a local oscillator 1105 and a range of multiple frequencies at the IF output 1106 is extracted and filtered to extract the desired signal output. In practice, the diced and packaged baluns are mounted on a common substrate such as a PCB and connected as needed to other components, active and passive, on the common substrate.

The invention having been disclosed in detail, it is clear that there are variations in keeping with the theme and spirit of the invention. To this end, there are other polymers that can achieve the low loss at high frequencies as well as provide for low capacitive coupling, while being readily adapted to large scale fabrication techniques. Such are considered within the purview of the present invention.

Claims:

1. A transformer having a substrate, a first metal spiral deposited on said substrate, a layer of dielectric material disposed on top of said substrate and said first metal spiral, and a second metal spiral deposed on top of said dielectric, said first metal spiral and said second metal spiral selectively electrically connected characterized in that:

said dielectric material is a layer of polymer insulator.

2. A transformer as recited in claim 1 wherein said polymer insulator is benzocyclobutene.

3. A transformer as recited in claim 1 wherein said polymer insulator has a loss tangent of approximately 0.002 and a dielectric constant of approximately 2.65.

4. A transformer as recited in claim 1 wherein said layer of dielectric is photosensitive benzocyclobutene, and further characterized in that a layer of non-photosensitive polymer is deposited on said layer of benzocyclobutene and said second metal spiral.

5. A transformer as recited in claim 1 further characterized in that said electrical interconnection between metal spirals is effected through selectively opened vias.

6. A transformer as recited in claim 5 further characterized in that:

said layer of polymer insulator has a dielectric constant of approximately 2.65.

said polymer insulator has a loss tangent of approximately 0.002.

8. A transformer as recited in claim 4 further characterized in that:

said layer of non-photosensitive polymer substantially encapsulates said second coil.

A transformer for high frequency applications having a multilayer thin film structure and a dielectric material disposed between coils increases the inductive coupling between the coils while at the same time reducing the capacitive coupling between the coils of the transformer. A glass substrate 201 has a first metal spiral 301 deposited thereon, and a layer of polymer insulator 601 is deposited thereon encapsulating the first metal spiral. A second metal spiral 701 is deposited on the layer of polymer and the process continues with a next layer of polymer material. The interconnection of the metal spirals to one another in the different layers is effected by the use of selectively etched grooves having vias 902 deposited therein. The present invention is specifically drawn to a balun transformer.

The use of the polymer preferably BCB as the dielectric has the functional advantage of very low loss due to absorption at microwave and rf frequencies, and yet this insulator allows for excellent inductive coupling while reducing greatly the capacitive coupling among the various layers of the device.

(Designated Figure 7)

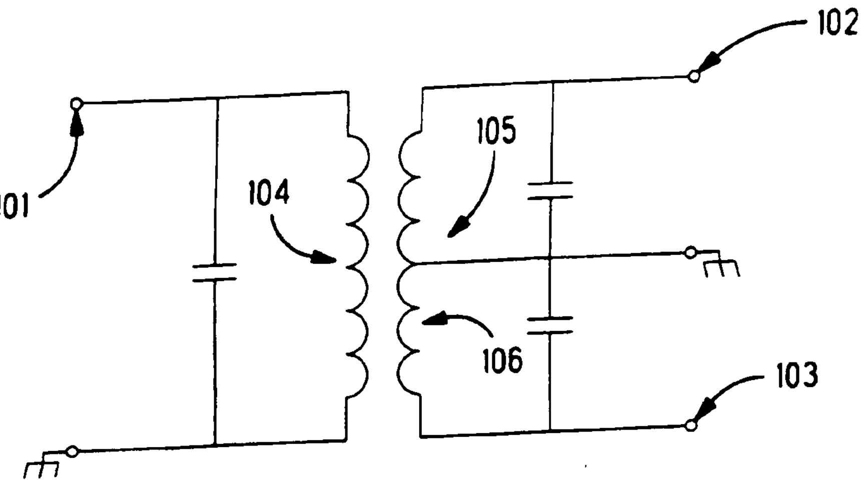
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Fig. 1

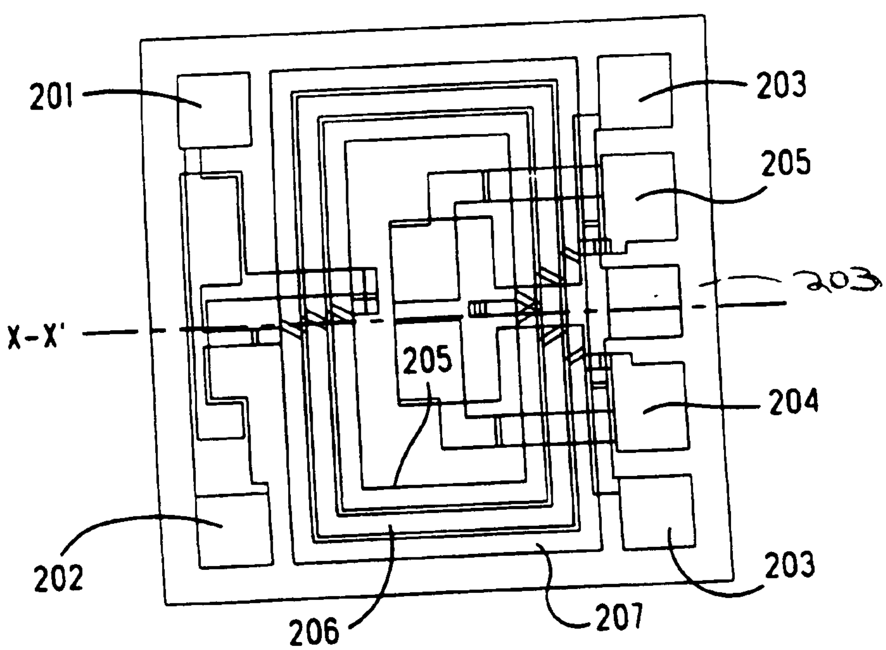
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Fig. 2

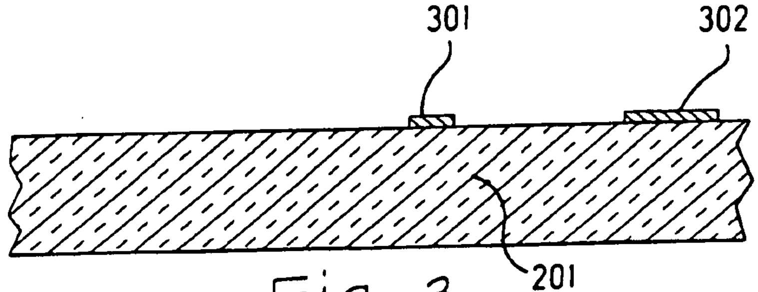

Fig. 3

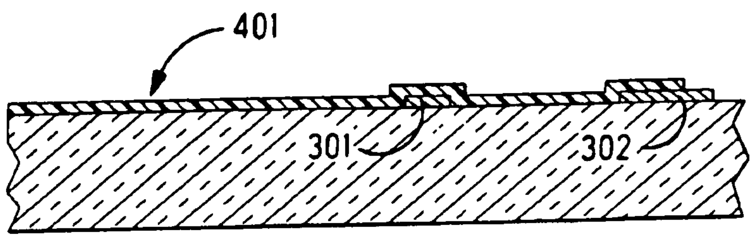

Fig. 4

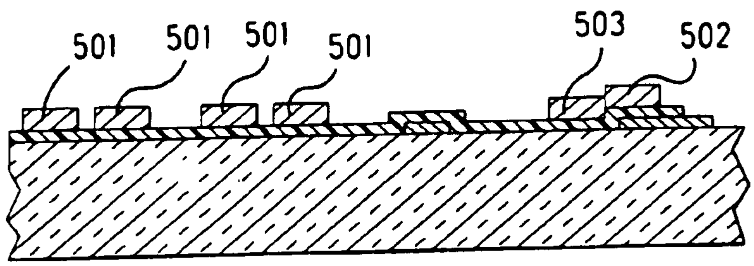

Fig. 5

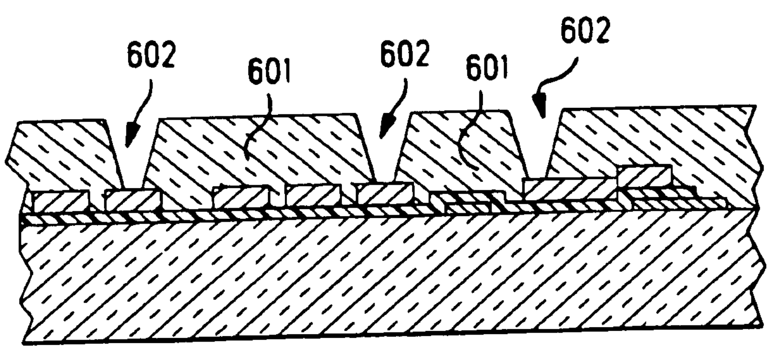

Fig. 6

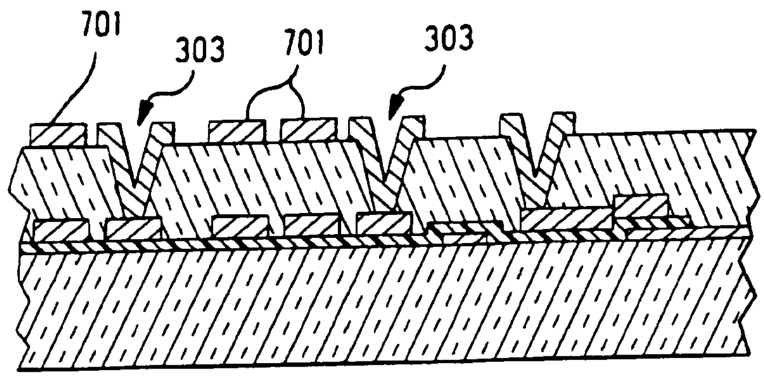

Fig. 7

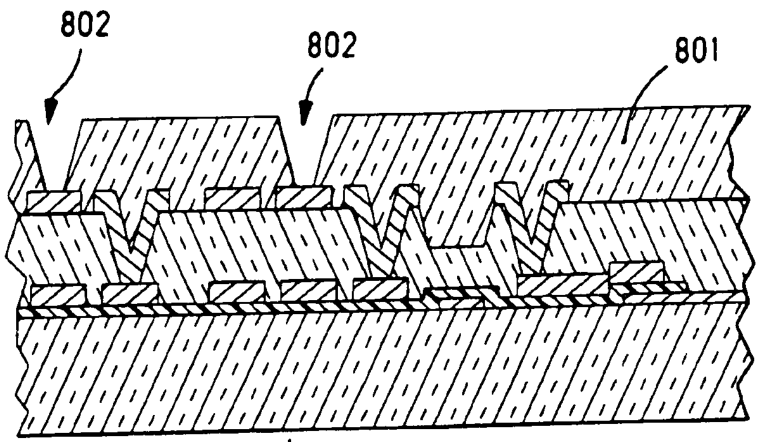

Fig. 8

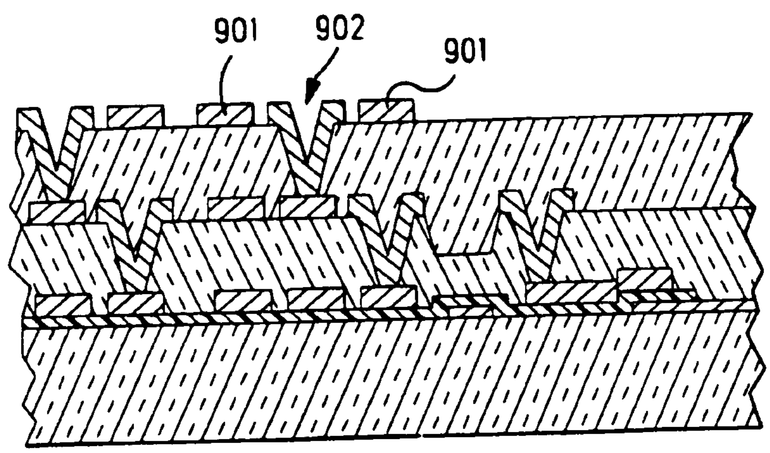

Fig. 9

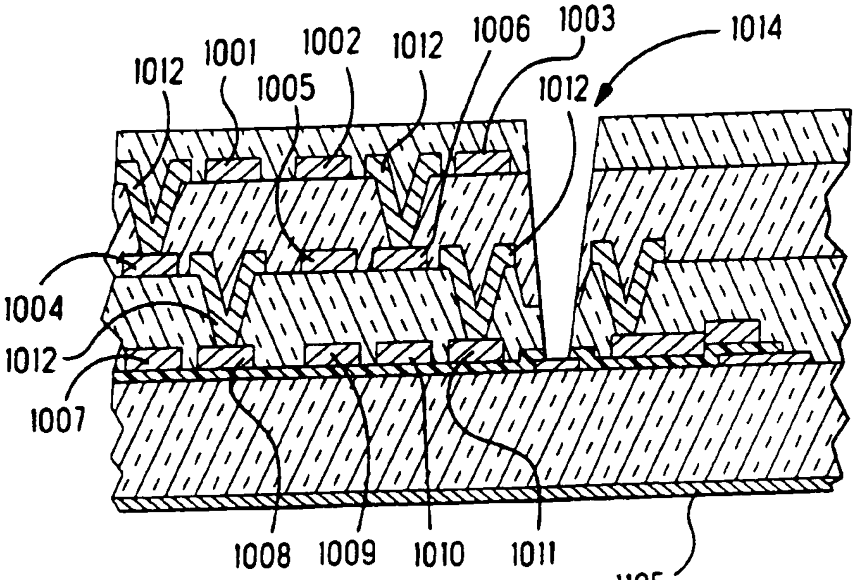
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Fig. 10

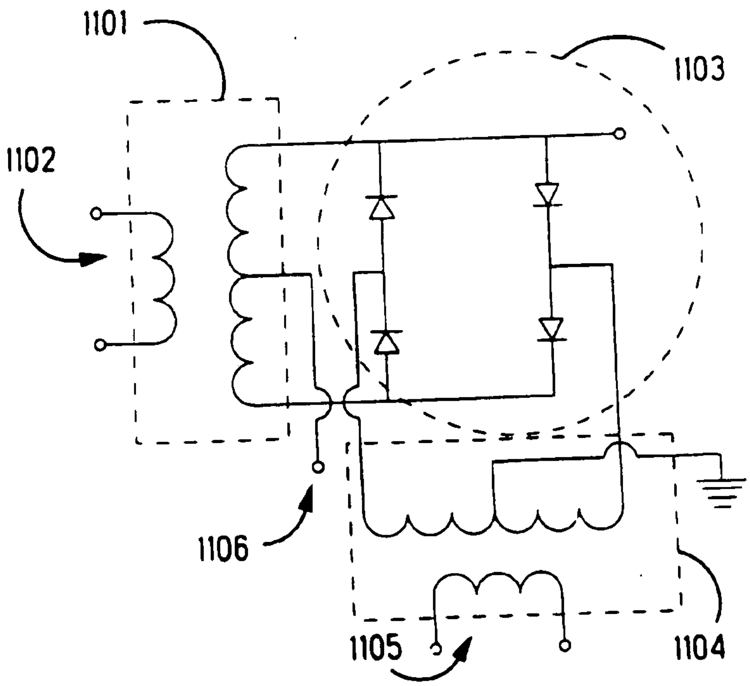
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Fig. 11

INTERNATIONAL SEARCH REPORT

International Application No
PCT/US 96/16876

A. CLASSIFICATION OF SUBJECT MATTER
IPC 6 H01F19/04 H01F27/28

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 6 H01F

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 5 363 081 A (BANDO MASAHIRO ET AL) 8 November 1994	1,5
A	see abstract see column 2, line 33 - line 42 see column 3, line 28 - line 44; figures 2,4,5 ---	4,8

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[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

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Date of the actual completion of the international search	Date of mailing of the international search report
20 January 1997	29. 01. 97

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INTERNATIONAL SEARCH REPORT

Inter nal Application No
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C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT		
Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	IEEE TRANSACTIONS ON COMPONENTS,HYBRIDS,AND MANUFACTURING TECHNOLOGY, vol. 16, no. 7, 1 November 1993, pages 714-719, XP000423131 CHINOY P B ET AL: "PROCESSING AND MICROWAVE CHARACTERIZATION OF MULTILEVEL INTERCONNECTS USING BENZOCYCLOBUTENE DIELECTRIC" cited in the application	1-3,5-7
A	see abstract see page 2, left-hand column see page 4, right-hand column, last paragraph - page 5, left-hand column; figure 1 ---	4
A	PROCEEDINGS OF THE ELECTRONIC COMPONENTS AND TECHNOLOGY CONFERENCE, WASHINGTON, MAY 1 - 4, 1994, no. CONF. 44, 1 May 1994, INSTITUTE OF ELECTRICAL AND ELECTRONICS ENGINEERS, pages 374-386, XP000479173 STRANDJORD A J G ET AL: "A PHOTOSENSITIVE-BCB ON LAMINATE TECHNOLOGY (MCM-LD)" see abstract -----	4

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International Application No
PCT/US 96/16876

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4	8	5858832.URPN.	USPAT	2004/08/13 09:24
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